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Articles

Nonbreeding Duck Use at Central Flyway National Wildlife Refuges

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Abstract

Within the U.S. portion of the Central Flyway, the U.S. Fish and Wildlife Service manages waterfowl on numerous individual units (i.e., Refuges) within the National Wildlife Refuge System. Presently, the extent of waterfowl use that Refuges receive and the contribution of Refuges to waterfowl populations (i.e., the proportion of the Central Flyway population registered at each Refuge) remain unassessed. Such an evaluation would help determine to what extent Refuges support waterfowl relative to stated targets, aid in identifying species requiring management attention, inform management targets, and improve fiscal efficiencies. Using historic monitoring data (1954–2008), we performed this assessment for 23 Refuges in Texas, New Mexico, Oklahoma, Kansas, and Nebraska during migration and wintering months (October–March). We examined six dabbling ducks and two diving ducks, plus all dabbling ducks and all diving ducks across two periods (long-term [all data] and short-term [last 10 October–March periods]). Individual Refuge use was represented by the sum of monthly duck count averages for October–March. We used two indices of Refuge contribution: peak contribution and January contribution. Peak contribution was the highest monthly count average for each October–March period divided by the indexed population total for the Central Flyway in the corresponding year; January contribution used the January count average divided by the corresponding population index. Generally, Refuges in Kansas, Nebraska, and New Mexico recorded most use and contribution for mallards *Anas platyrhynchos*. Refuges along the Texas Gulf Coast recorded most use and contribution for other dabbling ducks, with Laguna Atascosa and Aransas (including Matagorda Island) recording most use for diving ducks. The long-term total January contribution of the assessed Refuges to ducks wintering in the Central Flyway was greatest for green-winged teal *Anas crecca* with 35%; 12–15% for American wigeon *Mareca americana*, gadwall *Mareca strepera*, and northern pintail *Anas acuta*; and 7–8% for mallard and mottled duck *Anas fulvigula*. Results indicated that the reliance on the National Wildlife Refuge System decreased for these ducks, with evidence suggesting that, for several species, the assessed Refuges may be operating at carrying capacity. Future analyses could be more detailed and informative were Refuges to implement a single consistent survey methodology that incorporated estimations of detection bias in the survey process, while concomitantly recording habitat metrics on and neighboring each Refuge.

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Introduction

The National Wildlife Refuge System (NWRS) of the U.S. Fish and Wildlife Service (USFWS) was, in large part, established to conserve and enhance waterfowl populations and provide waterfowl hunting opportunities (Linduska 1964). Therefore, the NWRS devotes extensive resources on individual units (hereafter, Refuges) to acquire, manage, and restore habitats to benefit waterfowl. The extent of waterfowl use that Refuges receive and contribution of Refuges to waterfowl populations (i.e., the proportion of the Central Flyway population [CFP] supported at each Refuge) remains unassessed. Such an evaluation would help determine to what extent Refuges support waterfowl relative to stated targets, aid in identifying species requiring management attention, inform management targets, and improve fiscal efficiencies.

In North America, waterfowl are managed by four major administrative flyways: the Atlantic, Mississippi, Central, and Pacific flyways. Our focus was the Central Flyway, which encompasses portions of Montana, Wyoming, Colorado, and New Mexico east of the continental divide, plus Texas, Oklahoma, Kansas, Nebraska, South Dakota, and North Dakota, and the Canadian provinces of Alberta, Saskatchewan, and the Northwest Territories. Although the importance of wetlands in the Central Flyway to waterfowl conservation is nationally and internationally recognized (cf. Prairie Pothole, Rainwater Basin, Playa Lakes, and Gulf Coast joint ventures), our understanding of how these wetlands influence waterfowl distributions, relative abundances, migration chronologies, and migration patterns is lacking and hinders development of large-scale strategic waterfowl conservation efforts (USFWS 1999).

A majority of the > 100 Refuges located within the U.S. portion of the Central Flyway provide wetland habitat for breeding, migrating, and wintering waterfowl along with a wide variety of wetland-dependent migratory birds. In contrast to those located farther north, midlatitude and southern Refuges support few breeding ducks and mainly serve as stopover sites, staging areas, or wintering areas. Such areas are critical for the acquisition of nutrients necessary for waterfowl migration, reproduction, and survival (e.g., Newton 2004, 2006; Arzel et al. 2006; Kirby et al. 2008; Stafford et al. 2014). Given the continued loss and degradation of wetlands (Dahl 1990, 2011) and potential effects from a changing climate, information on the significance of the NWRS to waterfowl populations is critical for developing long-term management and conservation strategies for waterfowl.

Many Refuges in the Central Flyway conduct or previously conducted waterfowl surveys to document waterfowl abundance and use (Andersson et al. 2015). The USFWS typically surveys migrating and wintering waterfowl populations on Refuges throughout the Central Flyway from October through March, while surveys of breeding waterfowl are restricted to the

northern portions under different protocols (Smith 1995). An objective of many of these surveys has been to provide data to guide management decisions for an individual Refuge. But, as most sites have been conducting surveys for > 20 y (Andersson et al. 2015), these data can be useful in assessing long-term trends in waterfowl use of both individual and multiple Refuges combined, thus allowing us to quantify the contribution of habitats provided by Refuges to nonbreeding waterfowl management in the Central Flyway. Therefore, we 1) quantified and evaluated long- and short-term trends in Refuge use by migrating and wintering ducks in the Central Flyway and 2) assessed and evaluated long- and short-term trends in relative importance of Refuges to migrating and wintering ducks.

Methods

We contacted all Refuges within the United States' portion of the Central Flyway that were managed primarily for waterfowl, known to accommodate thousands of waterfowl, or provided ≥ 50 ha nonriverine wetland habitat on a yearly basis during migration and wintering periods to determine if they maintained historic waterfowl monitoring data. Among the sites that maintained regular monitoring data, we gathered all existing waterfowl survey data for the period October–March (hereafter, season) that were available at the time of collection. By restricting to this period, we were able to include the wintering phase and most of the fall and spring migrations for the majority of waterfowl species of the Central Flyway (Baldassarre 2014). Of the Refuges in North and South Dakota that responded to our requests for survey data, data were available for three locations in South Dakota and four in North Dakota. However, only one consistently conducted surveys throughout our focal period. Moreover, Refuges in this region are primarily managed for breeding waterfowl; therefore, we did not include data from North and South Dakota in the study. In total, we gathered data from 24 Refuges within the Central Flyway (Figure 1).

Data consisted of aerial and ground surveys, and the number of seasons with data ranged from 4 to 59 among Refuges (Andersson et al. 2015). The USFWS designated 23 of these sites as National Wildlife Refuges and one, Rainwater Basin, as a Wetland Management District. Three of the sites were located in Nebraska (North Platte, Crescent Lake, and Rainwater Basin), 3 in Kansas (Kirwin, Flint Hills, and Quivira), 6 in Oklahoma (Salt Plains, Washita, Deep Fork, Sequoyah, Tishomingo, and Little River), 2 in New Mexico (Bosque del Apache and Bitter Lake), and 10 in Texas (Texas Point, Attwater Prairie Chicken, McFaddin, Anahuac, Brazoria, San Bernard, Big Boggy, Matagorda Island, Aransas, and Laguna Atascosa). Although Matagorda Island is a unit of Aransas, it was surveyed independently and therefore, we considered it separately. Valentine National Wildlife Refuge in Nebraska also had historic waterfowl monitoring data, but no data were recent (i.e., within the last 40 y) and therefore, not included in the analyses. We included all available



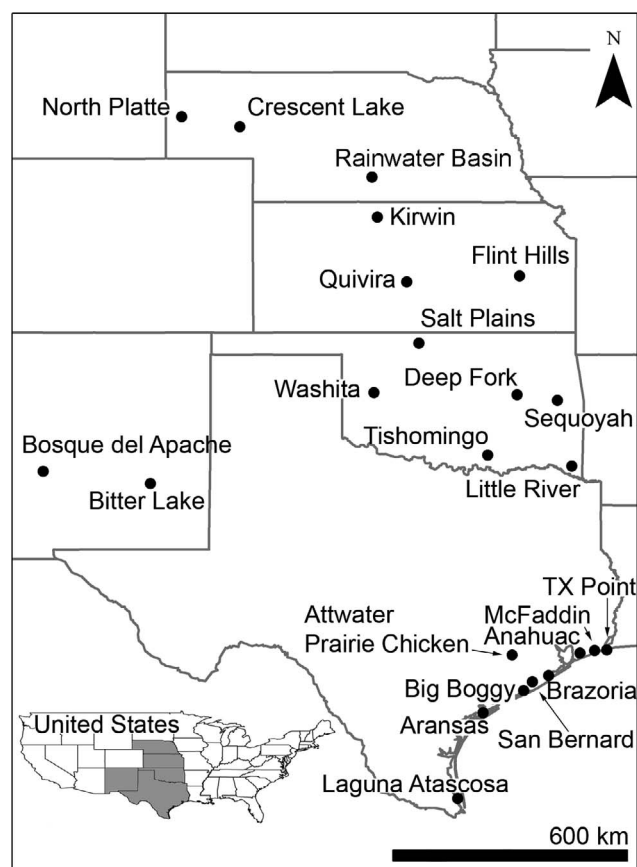


Figure 1. Map of the U.S. Fish and Wildlife Service National Wildlife Refuges and Wetland Management Districts within the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas), from which we gathered survey data (1954–2008) to assess Refuge duck use by gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, mottled duck *Anas fulvigula*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, redhead *Aythya americana*, scaup *Aythya affinis* and *Aythya marila*, total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas*, and total divers genera *Aythya*, *Melanitta*, *Clangula*, *Bucephala*, and *Oxyura*. Abbreviation represents Texas Point (TX Point).

survey data at the time of collection (i.e., throughout the 2007/2008 season) with the exception of Texas Refuges, for which the 2006/2007 season constituted the last season of available data. In two cases, Refuge personnel were unable to locate some of their existing survey data at the time of our data collection; 17 (1972/1973–1988/1989) out of 39 whole seasons of data for Bosque del Apache and 3 (1998/1999–2000/2001) out of 12 whole seasons of data for Bitter Lake were not available. We received monitoring data in paper form as copies of individual count sheets or count summaries, or in electronic form in a variety of database and spreadsheet formats. We transcribed data in paper format to digital format and carefully proofed them by comparing the entered data to the originals. We imported all data in electronic format directly without manual transcription. In all cases where the same data existed in more than

one data file, we used data from the earliest file as they were least altered by transcription and copying errors.

We limited our analyses to the following subset of species and groups: gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, mottled duck *Anas fulvigula*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, redhead *Aythya americana*, lesser and greater scaup *Aythya affinis* and *Aythya marila*, total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas*, and total divers genera *Aythya*, *Melanitta*, *Clangula*, *Bucephala*, and *Oxyura*. We combined lesser and greater scaup into one group (scaup) because they are closely related and difficult to visually separate in the field. We derived all group sums (scaup, total dabblers, and total divers) using raw count data for each individual survey prior to any other data manipulation. We propagated missing values through summations so that any sum based upon a missing count value resulted in a missing value. We excluded any individual survey discovered to be incomplete (i.e., when only a portion of the usual survey area was surveyed) from all analyses.

As expected, when working with long-term survey data from largely independent locations, conditions and practices varied among Refuges (Andersson et al. 2015). Analyses of changes over time at individual Refuges rest on the assumptions that survey methodology and spatial coverage remained consistent within the site over time. For the 15 Refuges with written survey protocols, these assumptions appeared acceptable, while for the remaining eight, they may or may not be (Andersson et al. 2015). However, all eight of those Refuges claimed to put emphasis on keeping their respective survey methods consistent through time and none were aware of any past changes in the methodology (Andersson et al. 2015). Moreover, if one were to exclude all Refuges without a written survey protocol from our analyses, there would only be a single qualitative change to the results and all overall conclusions would remain the same for all species and groups (K. Andersson, Oklahoma State University, unpublished results).

Differences in survey methodology, spatial coverage, or detection rate among individual Refuges can result in varying degrees of bias in the counts. This may skew the results for geographical distribution and overall trends for all Refuges with data combined. We can be fairly certain that no counts are biased high, as it is difficult to get complete survey coverage during ground counts and aerial counts often underestimate numbers (see Andersson et al. 2015). The group among which we could assume the bias to vary negligibly was Texas Refuges, which used the same methodology and where the same four individuals performed all surveys across the entire time series. Given that all Texas surveys were aerial surveys of areas without a forest canopy, the overall bias in these counts was likely also negligible. To verify the robustness of our results to varying bias among Refuges outside of Texas, we randomly assigned a negative count bias of 0, 10, 20, 30, or 40% to each of these sites, and calculated new overall slopes across all Refuges with nontrivial data (defined below). We chose the added bias based on the few sporadic bias estimates that existed for

some Refuges (all $\leq 30\%$; K. Andersson, Oklahoma State University, unpublished data). We repeated this procedure 1,000 times for each species, metric, and period analyzed. In no case did the addition of count bias produce an outcome qualitatively different from our initial results or alter any overall conclusions. Therefore, our metrics appeared robust to moderate deviations and inconsistencies in survey methodology, spatial coverage, and detection rate among Refuges. However, due to the nature of the underlying data, small differences in values were likely not meaningful for our application and we limited our interpretations to broad patterns.

During the data collection and entry process, we discovered a number of data sets where an area previously not surveyed had been incorporated into the survey space for a Refuge. If counts existed for each individual area, we subtracted counts for the added area from the total count to make it directly comparable to previous surveys. In most cases, however, no correction was possible and in those cases, we used the uncorrected data. A more common problem was the recording of unidentified ducks in varying proportions, sometimes including all of the counted individuals. This can lead to nonnegligible degrees of uncertainty in species counts among surveys. Following Andersson et al. (2015), we used the threshold of 10% unidentified birds as the cut-off point for when we considered a survey too unreliable. Thus, in cases where the proportion of unidentified individuals exceeded 10% of the total for that group of species or if the proportion was indeterminable, we excluded counts for the affected group of species from further analyses. The proportion of whole surveys that we excluded for this reason varied between 0 and 28% among Refuges. In cases where the proportion of unidentified individuals was $< 10\%$, any unidentified individuals were distributed proportionally among the existing species belonging to that group (Andersson et al. 2013). Because the survey frequency (i.e., weekly, biweekly, or monthly surveys) differed among Refuges, we calculated monthly count averages so that data were consistent among sites. These averages constituted the base units for all subsequent calculations and analyses. Two of our analyzed metrics depended on count data being available for all 6 mo within a season. Therefore, in order to minimize the loss of existing count data that would otherwise be discarded, we attempted to fill any remaining gaps (i.e., months without count averages) in the survey data through interpolation (described below).

All Refuges had at least one (range: 1–39) missing monthly count average filled by interpolation except for Rainwater Basin and Sequoyah, which offered no complete seasons at all, making interpolation impossible for these sites. The number of interpolations varied substantially among Refuges, species, and metrics (i.e., seasonal sum, peak contribution, and January contribution; see below for definitions; proportion of interpolated values: mean = 6%, range: 0–35%, across all data sets). Missing data were most common in months with low duck numbers (proportion within the 3 mo with the lowest average counts: mean = 66%, range: 42–100%) and chiefly a result of no survey data being available for

that month, or in some cases, due to survey data being discarded due to reasons described above (i.e., incomplete survey or proportion unidentified ducks being $> 10\%$ or indeterminable). Because most interpolations were for months with comparatively low duck numbers, any error introduced by the interpolations would likely have little effect on the overall patterns and conclusions. In fact, excluding all interpolated values from the analyses did not alter the overall pattern for any species and period, with the sole exception of mottled duck during the short term, which then exhibited an increased reliance on the NWRS over this period (K. Andersson, Oklahoma State University, unpublished results).

Interpolation method

To fill in data gaps resulting from missing count data for specific species (or groups of species) from specific months, in specific seasons, at specific Refuges, we used the following interpolation methodology (Andersson et al. 2013; an example with actual numbers is provided in Text S1, *Supplemental Material*). We estimated the relative proportion of counted birds for each month to the seasonal sum for the season with the missing count(s), by averaging calculated proportions for all seasons with complete data within 5 y of the season with a missing count. Thus, for each season with complete data (i.e., with data for all 6 mo) within 5 y of a season with one or more missing monthly count values, we calculated each month's proportion of the seasonal sum, $P_{m,s}$, according to

$$P_{m,s} = \frac{C_{m,s}}{C_{\text{Oct},s} + C_{\text{Nov},s} + C_{\text{Dec},s} + C_{\text{Jan},s} + C_{\text{Feb},s} + C_{\text{Mar},s}}, \quad (1)$$

where $C_{m,s}$ was the count for month, m , and season, s . We then took the average of the calculated proportions for each month across all the seasons with complete data within the interval. We used the resulting monthly proportions as the estimated count distribution for the season with the missing value(s). To estimate the missing monthly count value(s) for the season in question, we used each month with an existing count within the same season to calculate an estimate of the missing monthly value(s) according to

$$\hat{C}_x = \frac{C_{m_i}}{\hat{P}_{m_i}} \times \hat{P}_x \quad (2)$$

where, \hat{C}_x was the estimated missing count and \hat{P}_x was the estimated monthly proportion of the seasonal sum for the month with the missing count, x , and C_{m_i} was the count and \hat{P}_{m_i} the estimated monthly proportion of the seasonal sum for month m_i , with i ($1 \leq i \leq 5$) representing the months with existing counts within the season with the missing count(s). Thus, for each month with an existing count (m_i), C_{m_i}/\hat{P}_{m_i} represented an estimation of the seasonal sum for the season with the missing count(s), that when multiplied with the estimated monthly proportion of the seasonal sum for

the month with the missing count (\hat{P}_x), gave an estimate of the missing count (\hat{C}_x). As there was usually more than 1 mo with an existing count within the season with the missing count(s), this led to several different estimates of the missing value(s). Hence, we used the average of all estimates of the missing value(s) as the final estimate of the missing count(s). However, in some cases, an individual estimate of a missing value (\hat{C}_x) would yield an extremely high value due to an unusually high count (C_m) paired with a low estimated frequency (\hat{P}_m) for one of the months with an existing count (m_i). We addressed this problem by evaluating each individual estimate of a missing count against the average of all available actual counts for that month and discarding estimates that were unreasonably high. Because our goal was to remove obviously erroneous estimates while preserving high but potentially correct estimates, we only excluded estimates > 20 times the average of the actual counts. This procedure did remove all obviously erroneous values (e.g., an individual estimate of 367,122 American wigeon at Big Boggy in November of 2007, which was greater than twice the entire surveyed CFP at that time), while leaving high but plausible values intact. In these cases, we used the average of the remaining estimates of the missing value(s) as the final estimate of the missing count value(s).

Refuge use

We used the seasonal sum (i.e., the sum of the monthly count averages for October–March) as a measure of Refuge use. Thus, we calculated seasonal sums for all species and groups for all complete seasons at all locations (Data S1, *Supplemental Material*). We excluded incomplete seasons (i.e., seasons with one or more monthly count averages missing for which we were unable to interpolate values) from all analyses concerning Refuge use. We used least squares linear regression to obtain trends in Refuge use over time, both over the length of the entire data set (i.e., 1954/1955–2007/2008; hereafter, long term) and for the last 10 seasons of our study period (i.e., 1998/1999–2007/2008; hereafter, short term).

We analyzed distributions of positive and negative trends in Refuge use for individual species and groups of species across all Refuges with data. We used exact binomial tests under the null hypothesis of equal probability ($P = 0.5$) for a trend to be positive or negative (there were no instances with slope = 0) to identify system-wide patterns. For these analyses, we included only data sets for species–Refuge combinations that we considered nontrivial for the period in question. We considered any data set with at least five nonzero data points, less than 25% zeros, and an average seasonal sum of 500 or more for the time period in question nontrivial. Two locations, Rainwater Basin and Sequoyah, did not offer complete seasonal coverage for more than two seasons and hence, we performed no analyses of Refuge use for these locations. We calculated all proportional

Refuge use on use averages for the period in question, with the individual mean use value divided by the sum total of all the mean use values belonging to the same group. For example, for northern pintail, the seasonal mean use at Bosque del Apache over the long term was 27,164 (SE = 4,205) and the sum total of the use means for all the Refuges with data was 270,529. Thus, the proportional Refuge use by northern pintails accounted for by Bosque del Apache over the long term was 10%.

Refuge contribution

To evaluate the contribution of each Refuge to the Central Flyway duck population for each species and group, we relied on two indices. The first, peak contribution, used the greatest monthly count average for each complete season divided by the total population index for the Central Flyway in the corresponding year (Data S2, *Supplemental Material*). This index provided comparable values for all Refuges with data within the flyway. It also offered baseline index values regarding the magnitude of each Refuge's contribution to the CFP for each species. Another benefit was that peak contribution is robust against changes in migration chronology because it uses the greatest monthly count average regardless of when it occurs during the season. It does not, however, account for mortality, and can therefore both underestimate and overestimate the true proportion depending on when during the season the peak occurred. The second index, January contribution, used the January count average divided by the CFP index in the corresponding year (Data S3, *Supplemental Material*). The primary benefit of this index was that it was less influenced by mortality because the CFP index was also based on counts conducted in January. However, any contribution measure based on January counts would be uninformative when trying to evaluate the relative importance of Refuges whose peak use did not occur in January (e.g., Refuges that were not used extensively for wintering by these duck species). The uncertainty in peak contribution caused by mortality aside, we based all contribution values on monthly averages and they should therefore be considered minimum values.

Indices of the population sizes for these ducks in the Central Flyway came from summing the totals reported by the Mid-Winter Waterfowl Inventory (MWI) obtained from the USFWS (Data S4, *Supplemental Material*). Unfortunately, the MWI does not index redhead and scaup well, because large numbers of these species overwinter off the coast of the Gulf of Mexico (Baldassarre 2014). Therefore, we did not present contribution indices for these species or for the group sum total divers, because 89% of all the registered Refuge use by diving ducks was generated by those two species. Totals from the MWI were not available for the entire Refuge survey data series (1955–2008) for all focal species and total dabblers. Specifically, no MWI totals were available prior to 1959 for green-winged teal, 1971



for mottled duck, and 1980 for total dabblers. Consequently, some contribution data sets were bounded by the availability of MWI data.

Similar to the use analyses, we used least squares linear regression to obtain long- and short-term trends for both contribution indices and exact binomial tests to analyze the distributions of positive and negative trends across all Refuges with data. Two locations, Rainwater Basin and Sequoyah, did not offer complete seasonal coverage for more than two seasons and hence, we performed no analyses of peak contribution for these locations. Moreover, Rainwater Basin did not offer any January counts and thus, we performed no analyses of January contribution for this location. For the trend distribution analyses, we included only data sets for species–Refuge combinations that we considered nontrivial for the period in question. We considered any data set with at least five nonzero data points, less than 25% zeros, and an average peak count ≥ 200 birds or average January count ≥ 100 for the period in question as nontrivial. We calculated all proportional Refuge contribution values on contribution averages for the period in question, with the individual mean contribution values divided by the sum total of all the mean contribution values belonging to the same group. However, proportional Refuge contribution for peak contribution should be viewed cautiously, due to the nonnegligible risk of individual birds being included in more than one peak count at different Refuges throughout the season. For this reason, we did not interpret the sum totals for peak contribution averages across Refuges.

To quantify the collective contribution of the NWRS to wintering ducks within the mid to lower portion of the Central Flyway, we bootstrapped the raw January contribution values from each Refuge 1,000 times with replacement for each duck species and period. We then calculated the corresponding 1,000 sums across those Refuges and determined the mean and 95% confidence intervals of these sums (confidence intervals represented by the 2.5 and 97.5% quantiles). This approach provided estimates of the mean and confidence interval of the January contribution from all Refuges with data combined for each species over the long and short term.

Trends for all Refuges with data combined. We attempted to address the question of what proportion of the total CFP occurred on all Refuges with data combined by summing monthly averages across Refuges for each season. This proved impossible, however, due to the large variability among Refuges in terms of when surveys had been conducted. For every month in every season, there was always at least one Refuge lacking data and usually there were several. Therefore, to estimate the direction and approximate magnitude of the overall trends for the NWRS within the Central Flyway (hereafter, system-wide trends) for use, peak contribution, and January contribution, we summed the slope values for each species across Refuges. For this purpose, we used only slopes based on nontrivial data sets, as defined

above. We assumed a linear relationship between Refuge use or contribution and time, that our calculated slopes accurately described these trends for each location and species, and underlying counts were independent. While we recognize that these assumptions may be unfulfilled, the resulting slopes should indicate the direction and approximate magnitude of the true rates of change for the NWRS within the Central Flyway.

Before performing any analyses, we used visual inspection of plots of seasonal sum, peak contribution, and January contribution against time to identify notable outliers in individual species–Refuge data sets (e.g., Zuur et al. 2007). We chose visual plot inspection as the method of outlier detection because a standard statistical measure, for example, the Cook's distance measure (Cook 1977), frequently identified observations that were not outliers in a biological sense as statistical outliers in our highly variable data sets. We identified 22 seasonal sum data sets, 6 peak contribution data sets, and 11 January contribution data sets with one or more outliers. For each of these individual data sets in turn, we removed all identified outliers (no individual data set contained more than two outliers) and examined the effects on the system-wide trends. If the removal of the outliers significantly affected the interpretation of the system-wide trends (i.e., change of sign or marked change in magnitude), we removed the outliers from the individual species–Refuge data sets, calculated new trends, and used these instead of the original trends in all subsequent analyses. Of the 39 identified data sets with outliers, only one (with two outliers) had any significant influence on the system-wide trends: the seasonal sums data set for scaup at Matagorda Island. The exclusion or inclusion of outliers in the scaup data did not alter the signs of the system-wide trends or the trend distribution patterns in Refuge use for scaup. However, exclusion of the outliers did generate a marked decrease in magnitude for the system-wide Refuge use trend for the short term (Table 1). In all other cases, we took no action and used the original species–Refuge trends. We performed all statistical analyses using SAS 9.3 (SAS Institute, Inc., Cary, NC). We set the significance level to $\alpha = 0.05$. All tests were two-tailed.

Results

Refuge use—distribution

When comparing total duck use by the seven migratory duck species (i.e., not considering mottled duck) across all Refuges with data within the mid to lower portion of the Central Flyway, the most commonly supported species were green-winged teal, redhead, and mallard. Each species accounted for 22–24% of the total documented Refuge use over both periods (Table 1). Northern pintail accounted for 14–15% and gadwall for 10–11% of total use. Scaup and American wigeon recorded the least use with 5% apiece over the long term and 2–3% each over the short term.



Table 1. Changes in Refuge use for gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, mottled duck *Anas fulvigula*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, redhead *Aythya americana*, scaup *Aythya affinis* and *Aythya marila*, total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas*, and total divers genera *Aythya*, *Melanitta*, *Clangula*, *Bucephala*, and *Oxyura* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas) over the entire usable data set (1954/1955–2007/2008) and the last 10 seasons (1998/1999–2007/2008). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We present counts of positive (Pos) and negative (Neg) individual Refuge trends, sum total of averages across Refuges (STA), system-wide trends, and standardized system-wide trends (Std. trend) for Refuge use for each period. *P*-values are from exact binomial tests of the observed number of positive and negative trends under equal probability ($P = 0.5$) of trends being positive or negative. We limited trend distributions, STAs, and system-wide trends to including only individual Refuge trends with ≥ 5 nonzero data points, $< 25\%$ zeros, and an average seasonal sum ≥ 500 for the period in question. We calculated system-wide trends as the sum total of the relevant slope values for each species across all Refuges with data and standardized trends by dividing the system-wide trend by the corresponding STA. For scaup, we present results with and without outliers included (see Methods section for details).

Species	Entire data set						Last 10 seasons					
	Pos	Neg	<i>P</i>	STA	System-wide trend	Std. trend (%)	Pos	Neg	<i>P</i>	STA	System-wide trend	Std. trend (%)
American wigeon	4	13	0.049	100,351	−1,869	−1.9	8	7	1.000	68,798	3,944	5.7
Gadwall	16	3	0.004	200,975	8,398	4.2	10	8	0.815	243,116	2,986	1.2
Green-winged teal	13	6	0.167	478,400	9,676	2.0	4	13	0.049	522,940	−57,534	−11.0
Mallard	6	8	0.791	461,270	−8,625	−1.9	3	10	0.092	374,541	−26,328	−7.0
Mottled duck	0	7	0.016	10,754	−277	−2.6	3	3	1.000	6,688	62	0.9
Northern pintail	12	6	0.238	297,132	5,441	1.8	7	9	0.804	312,512	5,855	1.9
Redhead	7	4	0.549	475,601	5,620	1.2	4	5	1.000	490,440	−3,382	−0.7
Scaup	5	7	0.774	95,593	−3,115	−3.3	2	6	0.289	50,921	−7,875	−15.5
Scaup without outliers	5	7	0.774	49,360	−705	−1.4	3	5	0.727	30,999	−1,890	−6.1
Total dabblers	10	12	0.832	1,802,362	17,610	1.0	5	15	0.041	1,820,243	−99,184	−5.4
Total divers	9	10	1.000	642,981	3,027	0.5	7	9	0.804	597,933	868	0.1

Refuge use for total dabblers was geographically widespread but skewed toward the south (Tables S1 and S2, *Supplemental Material*). Anahuac received the most use, with 17 and 19% of all use for total dabblers over the long and short terms, respectively. Ninety percent of use for total divers was centered at three coastal Texas Refuges, with Laguna Atascosa and Matagorda Island accounting for > 50 and $> 30\%$ over both periods, respectively (Table S3, *Supplemental Material*).

Ninety-nine percent of mallard Refuge use was registered outside of Texas, with the four most heavily used locations (Bosque del Apache, Kirwin, North Platte, and Quivira) accounting for 70% of the total use in the long term and 83% in the short term (Tables S4 and S5, *Supplemental Material*; Figure 2). Five Refuges on the Texas Gulf Coast (Anahuac, Aransas, Brazoria, McFaddin, and San Bernard) accounted for $> 73\%$ of all gadwall use over both periods (Tables S6 and S7, *Supplemental Material*; Figure 2). Texas and New Mexico accounted for $> 87\%$ of the recorded American wigeon use over both periods, with three coastal Refuges (Aransas, Laguna Atascosa, and Matagorda Island) representing a total of 57 and 61% over the long and short terms, respectively (Tables S8 and S9, *Supplemental Material*; Figure 2). Greater than 74% of northern pintail use was recorded at Bosque del Apache, Aransas, Laguna Atascosa, and Matagorda Island in the short term, and by the same Refuges along with Quivira over the long term (Tables S10 and S11, *Supplemental Material*; Figure 2). Texas comprised $> 93\%$ of all green-winged teal use, with

Anahuac and McFaddin together accounting for $> 56\%$ for both periods (Tables S12 and S13, *Supplemental Material*; Figure 2). The nonmigratory mottled duck was only registered within Texas, and for both periods, Anahuac received the most use ($> 22\%$; Tables S14 and S15, *Supplemental Material*; Figure 2). For redhead, two coastal Refuges accounted for 95% of recorded use, with Laguna Atascosa receiving 64% and Matagorda Island 31%, for both periods (Table S16, *Supplemental Material*; Figure 2). Texas comprised $> 94\%$ of all documented scaup use for both periods, with Matagorda Island accounting for 53 and 45% and Aransas 26 and 23% over the long and short terms, respectively (Table S17, *Supplemental Material*; Figure 2).

Refuge use—trends

The system-wide trends in duck use demonstrated no clear pattern among species over either period. Gadwall, northern pintail, and total divers exhibited positive trends during both periods, while mallard and scaup displayed negative trends during both periods. The remaining four species and total dabblers reversed trends between periods. American wigeon and mottled duck demonstrated decreasing long-term trends and increasing short-term trends, while green-winged teal, redhead, and total dabblers exhibited increasing long-term trends and decreasing short-term trends (Table 1).

Over the long term, three trend distributions differed from random. American wigeon and mottled duck exhibited more negative trends than expected and gadwall more positive trends ($P < 0.05$ in all three cases;

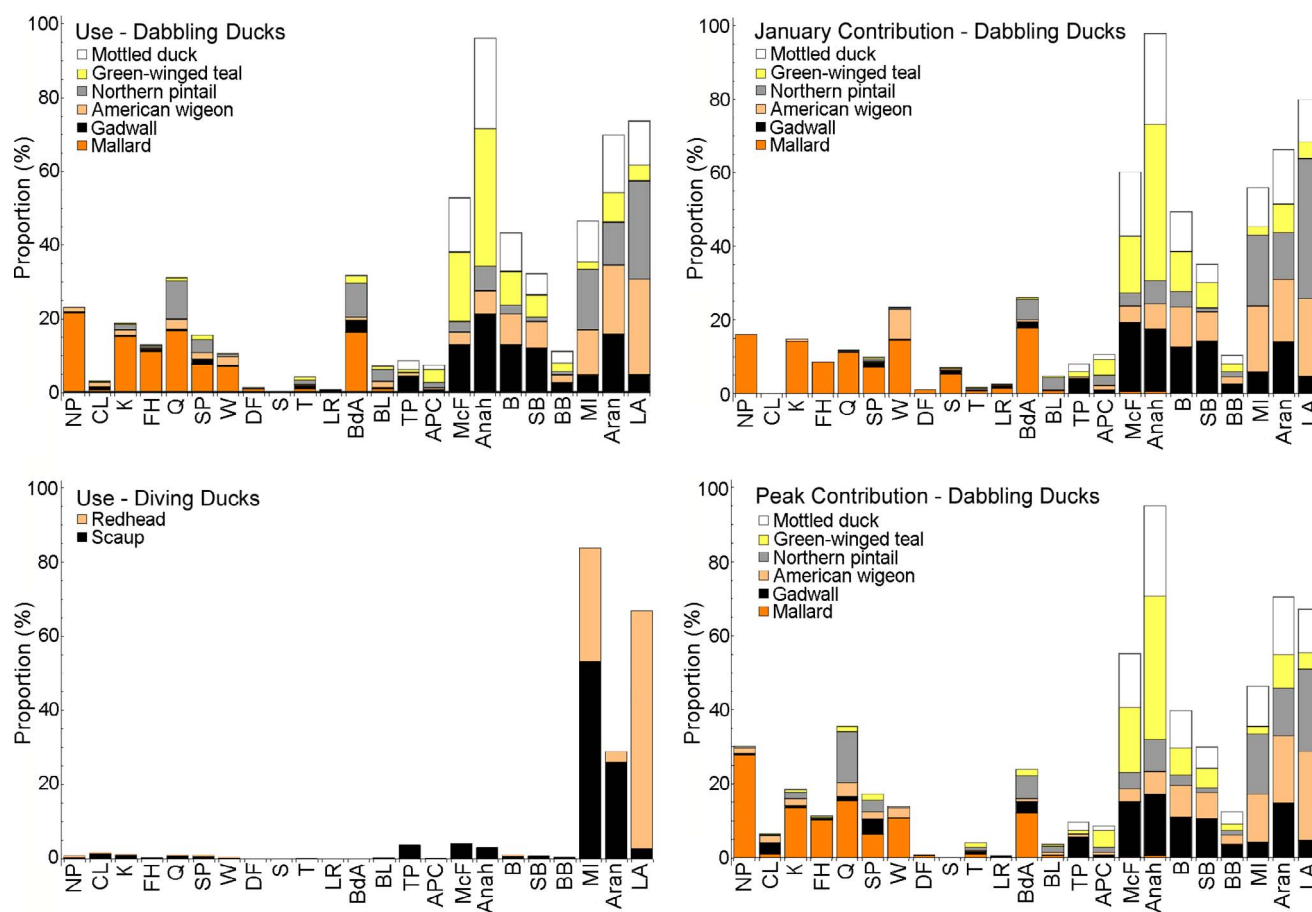


Figure 2. Bar plots visualizing average contribution of Refuges to the Central Flyway duck population indices, and the proportion of the total registered duck use recorded at individual Refuges in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas), 1954/1955–2007/2008 for gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, mottled duck *Anas fulvigula*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, redhead *Aythya americana*, and scaup *Aythya affinis* and *Aythya marila*. For use (calculated as the sum total of the monthly count averages for each migration and wintering season, October–March), each species segment of a bar represents the average proportion of the total use across all the Refuges that was recorded at that particular Refuge. For peak and January contribution, each segment represents the average proportion of that species' Central Flyway population index (estimated by the Mid-Winter Waterfowl Inventory) that was found at that Refuge during the month with the highest count average (October–March) and the month of January, respectively. We did not evaluate contributions for redhead and scaup because the Mid-Winter Waterfowl Inventory did not index these species well. Sequoyah lacked data to evaluate use and peak contribution. As the species segments within a bar are proportions based on different use totals or population indices, segments cannot be summed within bars (i.e., it is not meaningful to compare the total height of the bars among Refuges, only the height of the segments for the same species). Horizontal axis labels represent North Platte (NP), Crescent Lake (CL), Kirwin (K), Flint Hills (FH), Quivira (Q), Salt Plains (SP), Washita (W), Deep Fork (DF), Sequoyah (S), Tishomingo (T), Little River (LR), Bosque del Apache (BdA), Bitter Lake (BL), Texas Point (TP), Attwater Prairie Chicken (APC), McFaddin (McF), Anahuac (Anah), Brazoria (B), San Bernard (SB), Big Boggy (BB), Matagorda Island (MI), Aransas (Aran), and Laguna Atascosa (LA).

Table 1). Two trend distributions differed from random over the short term, with green-winged teal and total dabblers displaying more negative trends than expected ($P < 0.05$ in both cases).

Refuge contribution—distribution

Peak and January contribution for total dabblers was geographically widespread but generally skewed toward the south (Tables S1 and S2, *Supplemental Material*; Figure 2). Anahuac accounted for the greatest portion of total peak contribution (i.e., the sum of peak contribu-

tion averages across Refuges) with 17% over both periods. Together, Anahuac and Laguna Atascosa contributed most to total January contribution (i.e., the sum of January contribution averages across Refuges) over the long term with a combined 30%, while Anahuac dominated over the short term with 18%. Ninety-nine percent of the total peak contribution for mallard was registered outside of Texas, with Bosque del Apache, Flint Hills, Kirwin, North Platte, Quivira, and Washita accounting for 89% in the long term, and Bosque del Apache, Kirwin, North Platte, and Quivira recording 83%



Table 2. Mean (%) and 95% confidence interval (CI; represented by the 2.5 and 97.5% quantiles) from bootstrap estimates of the collective contribution of the National Wildlife Refuge System (as represented by the included Refuges) to wintering ducks within the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas) over each Refuge's entire usable data set (1954/1955–2007/2008) and the last 10 seasons (1998/1999–2007/2008) for gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, mottled duck *Anas fulvigula*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, and total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas*.

Species	Entire data set		Last 10 seasons	
	Mean	CI	Mean	CI
American wigeon	14.9	3.9–35.7	3.0	1.3–6.0
Gadwall	15.3	6.5–30.6	6.5	3.4–11.6
Green-winged teal	34.7	14.1–85.7	31.7	16.1–50.7
Mallard	6.9	3.1–13.0	6.9	4.0–11.7
Mottled duck	8.2	4.4–16.2	7.0	3.7–14.3
Northern pintail	11.7	4.9–19.9	12.0	5.6–19.7
Total dabblers	11.7	7.4–17.5	10.1	7.0–13.8

in the short term (Tables S4 and S5, *Supplemental Material*; Figure 2). Seventy-four percent of the total January contribution was recorded at Bosque del Apache, Kirwin, North Platte, Quivira, and Washita over the long term, while the same Refuges, excluding Washita, registered 79% over the short term.

Gadwall, American wigeon, and green-winged teal all exhibited considerable skew toward the south with Refuges on the Texas Gulf Coast representing 81–90% of total peak contribution and 88–94% of total January contribution each (Tables S6–S9, S12, and S13, *Supplemental Material*; Figure 2). Most notably, gadwall had 67% of total peak contribution and 77% of total January contribution originate from Anahuac, Aransas, Brazoria, McFaddin, and San Bernard in the long term. In the short term, these five Refuges comprised 80% of total January contribution, and, excluding McFaddin, 67% of total peak contribution. For American wigeon, Aransas, Laguna Atascosa, and Matagorda Island recorded 55% of long-term total peak contribution and, excluding Matagorda Island, 51% over the short term. Greatest long-term January contribution was registered at Aransas, Brazoria, Laguna Atascosa, and Matagorda Island (67% of total), while Anahuac, Aransas, Laguna Atascosa, and Matagorda Island accounted for 73% in the short term. For green-winged teal, 56% of long-term and 54% of short-term total peak contribution came from Anahuac and McFaddin (Tables S12 and S13, *Supplemental Material*; Figure 2). Anahuac, Brazoria, and McFaddin reported 68% of total January contribution long term, and together with San Bernard, 78% short term.

Northern pintail exhibited a similar pattern to the previous three species for January contribution, but a less uniform geographical distribution of Refuges contributing to total peak contribution. Sixty-five percent of total peak contribution for northern pintail originated at

Aransas, Laguna Atascosa, Matagorda Island, and Quivira in the long term, while 71% came from Aransas, Bosque del Apache, Laguna Atascosa, and Matagorda Island in the short term (Tables S10 and S11, *Supplemental Material*; Figure 2). Seventy percent of total January contribution for northern pintail arose from Aransas, Laguna Atascosa, and Matagorda Island in the long term and 69% in the short term. The nonmigratory mottled duck had 68% of long-term and 71% of short-term total peak contribution stem from Anahuac, Aransas, Laguna Atascosa, and McFaddin. These same Refuges, together with Brazoria and Matagorda Island in the long term and Matagorda Island in the short term accounted for 89 and 83% of the total January contribution for mottled duck over the long and short terms, respectively (Tables S14 and S15, *Supplemental Material*; Figure 2).

Bootstrap estimate of total January contribution. The bootstrap estimate of the collective contribution of the NWRS to wintering ducks within the mid to lower portion of the Central Flyway was greatest for green-winged teal, with 35% of the CFP index supported by the Refuges in January over the long term and 32% over the short term (mean estimates; Table 2). Refuges accounted for 15% each of American wigeon and gadwall CFP indices in January over the long term, but only 3 and 7%, respectively, over the short term. During both periods, 12% of northern pintail was registered within the NWRS, while for mallard and mottled duck the contribution was 7–8% over both periods (Table 2).

Refuge contribution—trends

All dabbler species and total dabblers displayed negative system-wide long-term peak contribution trends. In the short term, total dabblers and all dabbler species except American wigeon and gadwall displayed negative system-wide peak contribution trends (Table 3). For peak contribution, the trend distributions for gadwall and American wigeon in the long term and green-winged teal in the short term differed from random with more negative trends than expected ($> 83\%$ negative trends, $P < 0.008$ in all three cases).

With the exceptions of northern pintail over the long term and American wigeon over the short term, all dabbler species and total dabblers displayed negative system-wide January contribution trends for both periods (Table 4). For January contribution, the long-term trend distributions for gadwall and American wigeon, as well as the short-term trend distribution for total dabblers deviated from random distributions with more negative trends than expected ($> 76\%$ negative trends, $P < 0.027$ in all three cases).

Discussion

Using historic monitoring data, our analyses revealed patterns in duck use and the contribution of Refuge lands to duck populations. Unraveling these patterns remains important, given the amount of resources



Table 3. Changes in Refuges' contribution to the Central Flyway population index at peak Refuge use (i.e., peak contribution) for gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, mottled duck *Anas fulvigula*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, and total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas) over the entire usable data set (1954/1955–2007/2008) and the last 10 seasons (1998/1999–2007/2008). We defined peak contribution as the highest monthly count average within each season (October–March) divided by the corresponding Central Flyway population index (estimated by the Mid-Winter Waterfowl Inventory). We present counts of positive (Pos) and negative (Neg) individual Refuge trends, sum total of averages across Refuges (STA), system-wide trends, and standardized system-wide trends (Std. trend) for peak contribution for each period. *P*-values are from exact binomial tests of the observed number of positive and negative trends under equal probability ($P = 0.5$) of trends being positive or negative. We limited trend distributions, STAs, and system-wide trends to including only individual Refuge trends with ≥ 5 nonzero data points, $< 25\%$ zeros, and an average peak count ≥ 200 birds for the period in question. We calculated system-wide trends as the sum total of the relevant slope values for each species across all Refuges with data and standardized trends by dividing the system-wide trend by the corresponding STA.

Species	Entire data set						Last 10 seasons					
	Pos	Neg	<i>P</i>	STA (%)	System-wide trend (%)	Std. trend (%)	Pos	Neg	<i>P</i>	STA (%)	System-wide trend (%)	Std. trend (%)
American wigeon	2	17	0.001	59.4	−4.2	−7.1	10	6	0.454	14.0	1.3	9.0
Gadwall	2	17	0.001	33.4	−1.8	−5.4	10	8	0.815	14.2	0.4	3.0
Green-winged teal	9	10	1.000	60.5	−0.0	−0.0	3	15	0.008	55.7	−4.3	−7.8
Mallard	6	9	0.607	13.4	−0.3	−2.1	5	8	0.581	8.2	−0.5	−6.3
Mottled duck	1	6	0.125	13.5	−0.4	−2.8	2	4	0.688	9.3	−0.3	−2.7
Northern pintail	9	10	1.000	30.7	−0.5	−1.7	5	11	0.210	23.4	−0.4	−1.9
Total dabblers	6	16	0.052	21.2	−0.4	−1.9	6	14	0.115	15.2	−0.5	−3.6

devoted to acquisition and management of waterfowl habitats within the NWRS. When combined with other information describing duck conservation goals, duck conservation status, and the amount of available habitat for each species, the results inform Refuge management priorities for nonbreeding ducks in the mid to lower portion of the Central Flyway.

We found that diving duck use was concentrated to a few Refuges along the Texas Gulf Coast (i.e., Aransas, Laguna Atascosa, and Matagorda Island) while dabbling duck use was geographically more widespread. Mallards exhibited a more northerly distribution of use and contribution than the other dabbling duck species, for which Refuges along the Texas Gulf Coast generally dominated. That southerly Refuges registered the most use and greatest contribution (for species other than mallard) was expected because they are used extensively for wintering while most species primarily use more northerly locations as stopover sites during migration. Individual ducks spend more time on wintering locations than they do on stopover sites (Sedinger and Alisauskas 2014). Therefore, each individual is more likely to be counted more than once and larger numbers of individuals are more likely to be present during any given count at wintering locations, compared to stopover sites, thus generating greater Refuge use and contribution.

The average January contribution indexes the relative importance of a Refuge as a wintering site for the CFP of a particular species. Values > 0.01 indicate that, on average, $> 1\%$ of the January CFP (as indexed by the MWI) could be found wintering at this location. Similarly, a peak contribution average of the same magnitude indicates that at some point from October through March, $> 1\%$ of the January CFP was recorded on that Refuge. Contribution values exceeding 1% are noteworthy,

given the amount of waterfowl in the flyway and the relatively small size of Refuge lands. However, the MWI does not offer complete coverage of any species and thus underestimates the CFPs to varying degrees for each species. However, for most of the focal species, we believe the MWI coverage to be reasonably comparable. The exceptions include species for which a nonnegligible part of the CFP overwinters farther south and groups including such species: that is, green-winged teal and total dabblers (primarily due to the inclusion of blue-winged teal [*Spatula discors*]; Baldassarre 2014). Hence, caution is required if direct comparisons among species are made, and small differences are likely not informative. The proportion of the total recorded Refuge use for a certain species that a particular site accounts for gives another indication of the relative importance of that site for that species. For this metric, values above 10% are noteworthy, being twice the expectation from an equal distribution across Refuges (i.e., 4.5% given 22 Refuges). For example, Quivira, a traditional stopover site due to its location in central Kansas, showed no January contribution values $> 1\%$, while exhibiting peak contribution values $> 1\%$ for mallard, northern pintail, and American wigeon over the long term, as well as mallard over the short term. Proportional Refuge use $> 10\%$ was recorded for mallard during both periods and northern pintail over the long term. Thus, it would be pertinent for this Refuge to incorporate their historical importance for mallard, northern pintail, and American wigeon in their duck habitat management plans for the migration periods. Conversely, Aransas, a wintering Refuge located on the Texas Gulf Coast, displayed January and peak contribution values $> 1\%$ during at least one period for all dabbler species except mallard. Moreover, mottled duck, gadwall, northern pintail, American wigeon, and scaup registered proportional Refuge use $> 10\%$ apiece during

Table 4. Changes in Refuges' contribution to the Central Flyway population index in January (i.e., January contribution) for gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, mottled duck *Anas fulvigula*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, and total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas) over the entire usable data set (1954/1955–2007/2008) and the last 10 seasons (1998/1999–2007/2008). We defined January contribution as each year's January count average divided by the corresponding Central Flyway population index (estimated by the Mid-Winter Waterfowl Inventory). We present counts of positive (Pos) and negative (Neg) individual Refuge trends, sum total of averages across Refuges (STA), system-wide trends, and standardized system-wide trends (Std. trend) for January contribution for each period. *P*-values are from exact binomial tests of the observed number of positive and negative trends under equal probability ($P = 0.5$) of trends being positive or negative. We limited trend distributions, STAs, and system-wide trends to including only individual Refuge trends with ≥ 5 nonzero data points, $< 25\%$ zeros, and an average January count ≥ 100 birds for the period in question. We calculated system-wide trends as the sum total of the relevant slope values for each species across all Refuges with data and standardized trends by dividing the system-wide trend by the corresponding STA.

Species	Entire data set						Last 10 seasons					
	Pos	Neg	<i>P</i>	STA (%)	System-wide trend (%)	Std. trend (%)	Pos	Neg	<i>P</i>	STA (%)	System-wide trend (%)	Std. trend (%)
American wigeon	1	11	0.006	14.5	−1.2	−8.2	4	5	1.000	2.9	0.1	2.6
Gadwall	0	15	0.000	15.3	−1.0	−6.2	4	11	0.118	6.5	−0.3	−4.7
Green-winged teal	7	8	1.000	34.6	−0.2	−0.4	3	11	0.057	31.7	−3.3	−10.3
Mallard	6	9	0.607	6.9	−0.2	−2.5	3	11	0.057	5.3	−0.5	−9.1
Mottled duck	2	5	0.453	7.7	−0.2	−2.0	3	3	1.000	6.4	−0.1	−1.9
Northern pintail	9	6	0.607	11.7	0.0	0.3	4	9	0.267	12.0	−0.3	−2.6
Total dabblers	6	16	0.052	11.7	−0.2	−1.7	5	16	0.027	9.3	−0.6	−6.7

both periods. Waterfowl management at this Refuge favors these dabbler species and scaup.

Although relatively greater values of use and contribution for a particular Refuge indicate that it is an important location for the species in question, low values do not necessarily indicate the opposite. Food resources acquired by waterfowl at wintering and staging areas have been linked to individual fitness components through cross-seasonal effects (e.g., Raveling and Heitmeyer 1989; Ankney et al. 1991; Guillemain et al. 2008; Sedinger and Alisauskas 2014). Furthermore, because different species of waterfowl have different physiological requirements and employ different migration and breeding strategies, their resource requirements during migration and wintering differ (Jenni and Jenni-Eirmann 1998; Davis et al. 2014; Stafford et al. 2014). However, the current knowledge of which resources limit waterfowl and when they operate is incomplete, particularly during spring migration (Stafford et al. 2014). Hence, we cannot translate Refuge use and contribution into absolute values of importance due to lack of information describing the fitness consequences for individual birds during any given Refuge stay. It is possible that a stopover site registering moderate use and contribution may have equal or greater fitness impact than a wintering location recording high use and contribution, or vice versa. All surveys included in this analysis were also diurnal surveys, and some duck species forage away from their diurnal roosts to varying degrees during the migration and wintering period (Johnson et al. 2014). Moreover, the influence of Refuge habitats on waterfowl conservation is likely to vary with regional fluctuations in habitat availability and quality. We would expect Refuges to be of greater importance to ducks when regional conditions decline in quality (Stafford et al. 2014).

Interpretation of Central Flyway NWRS trends by species

We estimated temporal trends in duck use and contribution for each Refuge as well as system-wide trends describing the collective performance of the NWRS in the mid to lower latitudes of the Central Flyway. Because the system-wide trends summarize effects across Refuges, these metrics are likely more robust than trends for individual Refuges. Similarly, distributions of positive and negative use and contribution trends indicate how widespread particular patterns are among Refuges and help identify system-wide patterns. We summarized and interpreted these trends for each species and guild below. Granted, patterns of use and contribution may have changed in the 9 y following collection and analyses of these data.

Mallard. Mallard exhibited negative system-wide trends in Refuge use and both contribution indices across both periods. These negative trends appeared widespread over the short term, indicative of a system-wide process. This outcome suggests a mallard CFP that became increasingly dependent on habitat outside the NWRS during migration and wintering.

Mottled duck. Negative system-wide trends for both contribution indices over each period and a declining long-term Refuge use trend indicated that the mottled duck CFP became increasingly reliant on habitat outside the NWRS over time during October–March. The long-term negative pattern also occurred at a majority of individual locations. The lack of a pronounced pattern among short-term distribution trends indicated an uneven response among Refuges over this period.

Gadwall. All system-wide contribution trends were negative apart from the short-term peak contribution trend. Thus, despite increasing trends in Refuge use over

both periods, the gadwall CFP appeared to become increasingly dependent on habitat outside the NWRS during migration and wintering periods. This pattern appeared widespread among individual locations over the long term.

American wigeon. While dependence on the NWRS increased during the short term, as indicated by positive system-wide trends in use and contribution, this pattern was not widespread among individual Refuges. Conversely, American wigeon displayed long-term negative system-wide trends in use and both contribution indices; these trends were mirrored at the vast majority of Refuges. Therefore, as with previous species, reliance on habitat off Refuge has increased over the long term for American wigeon, with a possible reversal during later years.

Northern pintail. The system-wide, long-term trend in Refuge use was positive and reflected at a majority of individual sites. Peak contribution indicated only a small decrease in the importance of Refuge habitats while the January contribution did not display much change over the long term. Yet, negative January contribution trends were more prevalent than positive trends among individual locations for this period, while there was no clear pattern for peak contribution. In the short term, however, despite increasing use, both contribution indices indicated a decrease in the importance of the NWRS with negative trends being widespread among individual locations for both indices. Hence, the northern pintail CFP exhibited an increased dependency on habitat outside the NWRS over the short term and possibly also over the long term.

Green-winged teal. Despite a long-term increase in system-wide Refuge use that was mirrored at a majority of individual locations, the lack of notable change in any of the contribution indices for the same period suggested that there had been little change in the reliance on NWRS habitats for green-winged teal over this period. Both contribution indices exhibited virtually even trend distributions, reinforcing the lack of a long-term system-wide pattern. In contrast, during the short term, concomitant with a sharp decrease in use for green-winged teal, both contribution indices indicated notable decreases in overall Refuge importance. Moreover, the negative short-term trends were widespread among individual locations for all three measures, suggesting a system-wide phenomenon. Therefore, these data indicated a marked increase in reliance on habitats outside the NWRS during the short term.

Total dabblers. Despite the slight increase in system-wide Refuge use by total dabblers over the long term, there was a tendency for more negative than positive individual use trends for this period. This suggested that the system-wide long-term trend was dominated by a small set of individual trends. Conversely, total dabblers exhibited a widespread decline in Refuge use over the short term. Irrespective of time period, both contribution indices exhibited decreasing trends, with negative trends

dominating among individual locations. This suggested a dabbler population increasingly dependent on habitat outside the NWRS over time.

Redhead, scaup, and total divers. As the MWI does not provide a reasonable index of the January CFP for these taxa, we could not calculate contribution indices for them. Thus, observed patterns were difficult for us to interpret. Evaluating the NWRS's role in the conservation of these species requires improvements in population survey data.

A significant proportion of the enumerated January Central Flyway duck population was recorded at southern and mid-latitude Refuges in the Central Flyway during January (on average 3–35%, depending on species and time period). Our analyses also indicated that some Refuges supported relatively few ducks of any species, and that the reliance on the NWRS had decreased for most of these ducks. Causes of these patterns may include 1) Refuges managing ducks at carrying capacity, 2) decreases in the quantity or quality of relevant Refuge habitats over time, 3) altered landscapes surrounding Refuges (i.e., increasing isolation or increased availability of food from agricultural practices or habitat management by state and nongovernmental organizations outside the NWRS), or 4) changes in duck use in relation to large-scale climatic changes (i.e., changing migration and wintering patterns), either singly or in combination. Within the Central Flyway, the geographical footprint of Refuges is small, but because the total area surveyed did not change markedly during the considered period (a few sites experienced small increases due to areal expansion), changes in survey area cannot explain our results. Furthermore, as our analyses indicated a general pattern of widespread decline in proportional use of Refuge lands, the concomitant decrease in wetland area outside the NWRS (Dahl 1990, 2011) cannot offer an explanation either. Therefore, we handle these four possible explanations in turn.

The MWI data indicated that the January CFP decreased for some species and periods (e.g., mallard over both periods) while it increased for others (e.g., gadwall over both periods). If Refuges supported ducks at carrying capacity, the system-wide trends in contribution should run contrary to the trends in the January CFP (i.e., system-wide contribution trends rise while the MWI trends decline, or vice versa). For January contribution, trends opposite the MWI trends occurred for all migratory species except mallard, irrespective of period, and for mottled duck over the short term. Therefore, the evidence seemed consistent with a Central Flyway NWRS operating at carrying capacity during January for most dabbling ducks (with the exception of mallards). Further, among migratory species other than mallard, five out of seven peak contribution trends (with green-winged teal over the long term and gadwall over the short term as the exceptions) were in agreement with the carrying-capacity hypothesis. Thus, for the migratory dabbler

species other than mallard, the evidence for the carrying-capacity hypothesis appeared compelling. If the aim was to continue supporting the same or a greater proportion of Central Flyway duck populations within the NWRS, increasing the amount and quality of habitat on relevant Refuges seems appropriate.

Declines in the quantity or quality of available waterfowl habitats on Refuge lands over time could also explain the widespread reduction in contribution. As historic data describing past management practices and habitat availability and quality on these Refuges are essentially nonexistent (Andersson et al. 2015), it is impossible to evaluate the role of habitat and habitat management on the observed pattern. It follows that the lack of these data makes linking management actions with waterfowl numbers, and thereby management evaluation, impossible. It is regrettable that such data do not exist as it severely limits the utility of the historic waterfowl monitoring data. Considering the conservation mandate of the NWRS, it would benefit the USFWS to ensure that such habitat data are collected concomitant with waterfowl numbers in the future (Andersson et al. 2015).

Increasing isolation of existing habitats on Refuges due to destruction and degradation of wetlands in the surrounding landscape could cause similar patterns in Refuge contribution, as waterfowl abundances could decrease with increasing isolation (Brown and Dinsmore 1986; Andr  n 1994; Naugle et al. 2000). It is likely that Refuge isolation has increased over time, given the continuing wetland losses throughout the United States over the past century (Dahl 1990, 2011). It is also possible that habitat use outside of Refuges has increased over time due to increased availability of habitats, hence the declining contribution trends. For example, the documented redistribution of wintering waterfowl (particularly geese and mallards) over the past century in response to increased food resources (i.e., waste grain and cropping practices) from agricultural production of cereal grains is well recognized (e.g., Buller 1975; Smith et al. 1989; Baldassarre 2014). Several dabbling ducks, including mallard, northern pintail, American wigeon, and green-winged teal, rely on agricultural crops to varying degrees during migration and wintering, making it possible for them to refuel outside Refuges and other wetland habitats during migration and, most evidently in the case of mallard, overwinter farther north (Buller 1975; Smith et al. 1989; Baldassarre 2014). The construction of reservoirs within flight distance of agricultural fields has further enabled this development (Copelin 1961; Buller 1975; Hobaugh and Teer 1981). A logical consequence of this situation could be reduced reliance on Refuge habitats by mallards and other dabbling ducks during migration and wintering periods. However, as the general pattern of decreased reliance on NWRS habitats that we observed encompasses species that do not rely heavily on agricultural crops or whose wintering ranges have not changed markedly, this could only form a

partial explanation. A proper assessment of this habitat explanation requires detailed records of land use changes at various spatial scales across this section of the Central Flyway.

The last century has seen increasing temperatures (Hartmann et al. 2013) with corresponding changes in migration timing for many birds including waterfowl (Lehikoinen et al. 2004; Murphy-Klassen et al. 2005; Gordo 2007; Rubolini et al. 2007). Thus, it seems likely that changes in migration chronology among Central Flyway waterfowl may also have occurred. Indeed, chronology changes have already been detected in many species of ducks in the Central Flyway (Andersson et al. 2013), but it is unlikely that this response is the sole source of the observed pattern in Refuge contribution.

Our results can help inform nonbreeding duck management objectives for Refuges collectively and individually within the Central Flyway. Such objectives include the types of ducks to manage for and their relative amounts. When combined with energetic models, this information can define habitat and management objectives (King et al. 2006). Armed with this information, Refuges could design how to operate as a system to meet the migratory and wintering needs of ducks within the Central Flyway, instead of each location attempting to manage multiple species of ducks independently. Such a plan would enable individual Refuges to favor management for a given species' biological needs, based on their ecological setting (Fredrickson and Taylor 1982; Euliss et al. 2004). For example, some Refuges may manage more for northern pintails and others for scaup, while working within an overarching design to ensure that they address the desired abundance goals for all waterfowl. Together, Refuges could target those waterfowl in decline and reverse the general pattern of decreasing contribution across species. Implementing this strategy should improve waterfowl habitats, promote fiscal efficiency, enhance waterfowl populations, and improve harvest opportunities.

Data quality and analytical assumptions

In the Methods section, we identified issues with the Refuge survey data and explained how we addressed them. These issues included differing survey methodology across Refuges, absence of written protocols, data gaps, and variable detection. Previously, we evaluated these same data and discussed these issues, making calls for improvements, in particular emphasizing the need for standardized survey protocols (Anderson et al. 2015).

To our knowledge, the MWI is the only available source of population indices for the Central Flyway during the period of Refuge surveys (1955–2008). Despite the perceived limitations of the MWI data (see Eggeman and Johnson 1989; Heusmann 1999; Smith et al. 1989), the MWI appears to provide adequate indices for the total CFP for species that mainly overwinter within it (cf. Conroy et al. 1988; Baldassarre 2014;

Ringleman et al. 2017). Although the survey methodology for the Texas portion of the MWI underwent some changes in 1997–2001 (summarized below), the resulting totals for Texas do not show any apparent pattern as a result (Haukos 2008; Figure S1, *Supplemental Material*). Therefore, it is unlikely that these methodological changes would invalidate any of our overall results.

Quantitative data on actual survey effort for the Central Flyway MWI was not available to us. However, documented deviations in effort from the prescribed MWI protocols were few for New Mexico, Oklahoma, and Texas, where > 90% of all species except mallard were counted (see Haukos [2008] for details on all known deviations). Further, as no major changes in survey methodologies have occurred outside of Texas and there have not been any other systematic changes in effort that we are aware of, any variation in effort likely had little impact on our application of MWI totals. In 1997, Texas began phasing in a statewide transect survey to replace the original cruise survey of the state and transect survey covering the upper Texas Gulf Coast. By 2001, the statewide MWI transect survey was fully operational. The only area not covered via transects was the playa lakes portion of the northwest (High Plains region), which was surveyed using a random subset of playas.

Analyzing and presenting results from these data are not condoning survey malpractices. Instead, our perspective is that these data contain valuable information that can benefit migrating and wintering waterfowl in the Central Flyway. Owing to the nature of these data, we limited our analyses and interpretations to broad patterns in 1) the distribution of duck use and contribution across Refuges and 2) changes in the collective importance of Refuges to ducks over time. We consider this study to generate a general, baseline context of Refuge waterfowl use and contribution in the Central Flyway. This study should steer future work for advancing waterfowl stewardship, and inspire biologists to remediate data deficiencies and minimize assumptions so future efforts become more specific, thorough, and informative. Until these fixes happen, nonbreeding waterfowl survey data from Refuges will remain limited to general interpretation and risk being viewed skeptically by many in the broader wildlife biological community.

Management implications

Our work unveils interesting trends in utilization and contribution but lacks data to elucidate causes of patterns. To remediate this situation, a standardized system-wide monitoring program capable of linking habitat conditions and management (on and within the forage flight distance of Refuges; Johnson et al. 2014) to waterfowl numbers is needed. As proposed by the U.S. Department of the Interior, the Inventory and Monitoring Initiative of the NWRS clearly emphasizes decision-based monitoring within an adaptive manage-

ment framework (Williams et al. 2009; USFWS 2012). Quantifying habitat type, quality, amount, effects of management actions, and waterfowl response (i.e., abundance) would reveal how well Refuges (individually and as a system) are meeting their waterfowl abundance and habitat goals, and the extent to which habitat management influences them. The Integrated Waterbird Management and Monitoring Initiative is a good example of a current effort to link habitat availability to waterbird counts using standardized protocols across wetland (local), state (regional), and national scales (Loges et al. 2014).

Supplemental Material

Please note: The Journal of Fish and Wildlife Management is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author.

Data S1. All data for the analysis of Refuge use by gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, mottled duck *Anas fulvigula*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, redhead *Aythya americana*, scaup *Aythya affinis* and *Aythya marila*, total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas*, and total divers genera *Aythya*, *Melanitta*, *Clangula*, *Bucephala*, and *Oxyura* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas), 1954–2008. We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). Although Matagorda Island was not a unique Refuge, but a unit of Aransas, it was surveyed independently and therefore we considered it a separate unit.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S1> (102 KB XLS).

Data S2. All data for the analysis of Refuges' peak contribution to the Central Flyway population index for gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, mottled duck *Anas fulvigula*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, and total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas), 1954–2008. We defined peak contribution as the highest monthly count average within each migration–wintering season (October–March) divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index. Although Matagorda Island was not a unique Refuge, but a unit of Aransas, it was surveyed independently and therefore we considered it a separate unit.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S2> (104 KB XLS).

Data S3. All data for the analysis of Refuges' January contribution to the Central Flyway population index for



gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, mottled duck *Anas fulvigula*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, and total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas), 1954–2008. We defined January contribution as each season's (October–March) January count average divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index. Although Matagorda Island was not a unique Refuge, but a unit of Aransas, it was surveyed independently and therefore we considered it a separate unit.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S3> (103 KB XLS).

Data S4. Mid-Winter Waterfowl Inventory totals for the Central Flyway area in the United States by state and year for gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, mottled duck *Anas fulvigula*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, and total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas*, 1955–2008. We used sum totals across states for each species or group of species as indices of their respective Central Flyway population.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S4> (79 KB XLS).

Text S1. Detailed numerical example of the method we used to interpolate missing monthly count averages for specific species (or groups of species), in specific seasons, at specific Refuges in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas), 1954–2008.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S5> (20 KB DOCX).

Table S1. Long-term (i.e., over the entire data set; 1954/1955–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S6> (21 KB DOCX).

Table S2. Short-term (i.e., over the last 10 seasons; 1998/1999–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for

total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. There were no short-term survey data for Crescent Lake.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S7> (16 KB DOCX).

Table S3. Refuge use for total divers genera *Aythya*, *Melanitta*, *Clangula*, *Bucephala*, and *Oxyura* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas) over the long and short terms (i.e., over the entire data set [1954/1955–2007/2008] and the last 10 seasons [1998/1999–2007/2008], respectively). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. There were no complete seasons with data for Sequoyah.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S8> (15 KB DOCX).

Table S4. Long-term (i.e., over the entire data set; 1954/1955–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for mallard *Anas platyrhynchos* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S9> (16 KB DOCX).

Table S5. Short-term (i.e., over the last 10 seasons; 1998/1999–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for mallard *Anas platyrhynchos* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New

Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. There were no short-term survey data for Crescent Lake.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S10> (16 KB DOCX).

Table S6. Long-term (i.e., over the entire data set; 1954/1955–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for gadwall *Mareca strepera* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S11> (16 KB DOCX).

Table S7. Short-term (i.e., over the last 10 seasons; 1998/1999–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for gadwall *Mareca strepera* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. There were no short-term survey data for Crescent Lake.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S12> (16 KB DOCX).

Table S8. Long-term (i.e., over the entire data set; 1954/1955–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for American wigeon *Mareca americana* in the mid to lower

portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S13> (17 KB DOCX).

Table S9. Short-term (i.e., over the last 10 seasons; 1998/1999–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for American wigeon *Mareca americana* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. There were no short-term survey data for Crescent Lake.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S14> (16 KB DOCX).

Table S10. Long-term (i.e., over the entire data set; 1954/1955–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for northern pintail *Anas acuta* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. There were no northern pintails recorded at Little River.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S15> (16 KB DOCX).

Table S11. Short-term (i.e., over the last 10 seasons; 1998/1999–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for northern pintail *Anas acuta* in the mid to lower portion



of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. There were no short-term survey data for Crescent Lake and no northern pintails recorded at Little River.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S16> (16 KB DOCX).

Table S12. Long-term (i.e., over the entire data set; 1954/1955–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for green-winged teal *Anas crecca* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S17> (16 KB DOCX).

Table S13. Short-term (i.e., over the last 10 seasons; 1998/1999–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for green-winged teal *Anas crecca* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. There were no short-term survey data for Crescent Lake.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S18> (16 KB DOCX).

Table S14. Long-term (i.e., over the entire data set; 1954/1955–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for

mottled duck *Anas fulvigula* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. No Refuges outside Texas recorded any mottled ducks during their surveys.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S19> (14 KB DOCX).

Table S15. Short-term (i.e., over the last 10 seasons; 1998/1999–2007/2008) use of Refuges and contribution of Refuges to the Central Flyway population index for mottled duck *Anas fulvigula* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We defined peak and January contributions as the highest monthly count average and the January count average within each season divided by the corresponding Central Flyway Mid-Winter Waterfowl Inventory population index, respectively. We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge and metric. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. No Refuges outside Texas recorded any mottled ducks during their surveys.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S20> (14 KB DOCX).

Table S16. Refuge use for redhead *Aythya americana* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas) over the long and short terms (i.e., over the entire data set [1954/1955–2007/2008] and the last 10 seasons [1998/1999–2007/2008], respectively). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. There were no complete seasons with data for Sequoyah and no redheads recorded at Little River.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S21> (15 KB DOCX).

Table S17. Refuge use for scaup *Aythya affinis* and *Aythya marila* in the mid to lower portion of the Central Flyway (Nebraska, Kansas, Oklahoma, New Mexico, Texas) over the long and short terms (i.e., over the entire data set [1954/1955–2007/2008] and the last 10 seasons [1998/

1999–2007/2008], respectively). We estimated Refuge use by the sum total of the monthly count averages for each migration and wintering season (October–March). We present sample size, mean, least squares linear regression slope, and r^2 for each Refuge. We have included corresponding data for Central Flyway survey totals from the Mid-Winter Waterfowl Inventory (MWI) for comparison. There were no complete seasons with data for Sequoyah.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S22> (18 KB DOCX).

Figure S1. Mid-Winter Waterfowl Inventory totals for Texas scaled by Oklahoma totals to control for population changes (i.e., scaled counts) for gadwall *Mareca strepera*, American wigeon *Mareca americana*, mallard *Anas platyrhynchos*, green-winged teal *Anas crecca*, northern pintail *Anas acuta*, and total dabblers genera *Aix*, *Spatula*, *Mareca*, and *Anas*, 1980–2008. While Texas gradually implemented changes to their Mid-Winter Waterfowl Inventory methodology during 1997–2001, the methodology in Oklahoma remained unchanged during the entire period. As counts for both states should respond proportionally to population changes, any significant changes in the Texas totals due to altered methodology should be revealed in the scaled counts. There was no obvious or consistent pattern among species as one would expect if the changes in the Texas methodology significantly affected the tallied duck numbers. Mottled duck *Anas fulvigula* was not included because it did not occur outside of Texas.

Found at DOI: <http://dx.doi.org/10.3996/042017-JFWM-033.S23> (39 KB DOCX).

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